5.0 WATER SUPPLY FOR HOH RIVER FISH

Anadromous salmonids are an important cultural and commercial resource for the Hoh Tribe. These salmon and steelhead runs may be affected by climate change and increased frequency of drought conditions in the future. Low river flows during late summer and fall of 1987 and 2002 impeded fish passage in the Hoh River. Washington Department of Fish and Wildlife (WDFW) closed fishing on the Hoh River during low flow periods in these years to reduce impacts to returning adult spawners. Extrapolation of past hydrologic trends suggests an elevated frequency and duration of these low flow occurrences in the future, increasing the possibility of detrimental impacts to Hoh River fisheries. This report discusses possible solutions for maintaining healthy anadromous populations within the Hoh River.

The Hoh Basin drains approximately 299 square miles of land, mostly in Jefferson County, Washington (Figure 5-1). The Hoh River itself is a large, glacially influenced river with its headwaters in the Olympic Mountains. Approximately half of the Hoh River drainage is located within the Olympic National Park.

The Hoh River generally flows from east to west with the Pacific Ocean on the Washington coast at its terminus. River flow within the Hoh and its tributaries is maintained by the generous amount of rainfall the watershed receives; an average of 150 inches of annual precipitation (NOAA NCDC 2005) makes it one of the wettest regions in the United States. Numerous springs, and mountain glacier and winter snow-pack melt and run-off sustain streamflows during the summer months. These cool, clean waters establish important habitat for the anadromous and resident salmonid populations that use the basin for spawning and rearing.

5.1 Fish Inventory and Distribution

Life histories for anadromous salmonids of the Hoh River are described in Table 5-1. Nearly all salmon and steelhead stocks have natural production (wild spawning) with very few introductions of outside stocks. Fish numbers and the relative health of fish stocks are estimated by measuring the stock's spawning escapement and adding the estimates of that stock's contribution to each fishery throughout its migratory range for each run of fish (to the extent possible). This is then compared to the run size trends from year to year over a large number of years (especially for coho which all result from a single year brood escapement. A more rigorous method for Chinook and steelhead requires doing the previous assessment each year, and assigning each cohort through sampling of the fish returning ages (the same sets of siblings that return at different ages in successive return years) to the same class that results from one parental escapement. (For example, the 1977 Hoh fall Chinook escapement broodyear returns would be assessed as a class by assessing the number of 1980 Hoh river returns of that class [number of 3 year olds in the 1980 Hoh returning run], 1981 [the number of 4 year olds], 1982 [the number of 5 year olds], 1983 (the number of 6 year olds], and 1984 (the number of 7 year olds] returns.) As a terminal run, the number of fish caught in the tribal and sport fisheries at (or near) the river's mouth plus the escapement (as determined by seasonal spawner surveys) provides a relatively accurate estimate of that year's run size returning from the ocean.

The spring/summer Chinook run is the largest population of early running Chinook on the Olympic Peninsula, the majority of this stock spawns above the junction of the South Fork and ONP boundary (RM 30.0) in the North Fork up to RM 48.0 , in the lower 9 miles of the South Fork, and from the junction of the South Fork to the Hoh Oxbow (RM 15.2). The stock is the smallest of the commercially harvested runs on the Hoh River, though it occasionally dips below its escapement floor. It has remained relatively healthy compared to its historic levels and compared to fall Chinook, though that is a larger run. More of the life history stages of the earlier Chinook, which spawn higher in the system are located within ONP habitat, while most of the life history of the fall Chinook lies outside of park waters. Natural escapement levels for spring/summer Chinook range from approximately 500 to 2,500 fish annually with an average of approximately 1,500 from 1976 to 2004. The terminal run size for spring/summer Chinook has ranged from approximately 500 to 7,000 and averaged approximately 2,400 over the same period (Jim Jorgensen, Hoh Tribe, personal communication).

Most fall Chinook spawning occurs below the Olympic Park Hoh Ranger Station at RM 35.3 on the North Fork, but mostly below the Park boundary and RM 30.0, along the South Fork mostly below the Olympic Park boundary near RM 5.0, down the South Fork and Mainstem, within all the larger tributaries below these locations as far down as the G&L shake road at RM 3.0. Winfield Creek and the South Fork Hoh River also support significant fall Chinook spawning with lesser numbers spawning in Nolan, Owl, and Mt. Tom Creeks. Recent information (Jim Jorgensen, Hoh Indian Tribe, personal communication) on the health of the fall Chinook stock shows a decline in spawning activity within the Hoh River tributaries and the side-channels of the middle Hoh River that have been impacted by sluice-outs and channel instability. Since 1976, non-hatchery escapement numbers for fall Chinook have ranged around an average of 2,932; non-hatchery terminal run size for fall Chinook has averaged 4,131 (Jim Jorgensen, Hoh Tribe, personal communication).

Hoh chum production is insignificant which is mostly attributed to the lack of a significant estuary compared to the Grays Harbor where chum are strong. Winter Steelhead have maintained at healthy levels within the Hoh system. Their juvenile freshwater residence is among the longest for salmonids which have a directed harvest by tribal and recreational fisheries.

5.2 Limiting Factors

The term "limiting factors" refers to any condition that negatively affects the salmonid population abundance. Limiting factors may include water quantity, water quality, and other physical habitat characteristics such as pools, riffles, large woody debris, riparian condition, sediment levels in spawning gravels, etc.. Variations in these conditions influence the population size of the salmonid species at various life history stages. The Hoh River basin is affected by a number of limiting factors, but especially low streamflow during summer and fall months. These low streamflows can affect upstream migration, particularly of fall Chinook. Low flows can affect fish passage in the following ways:

- At the river's mouth – Most fish come in on the tides into the river during low flows, but will stack up below certain shallow riffles in the fall.
- Flows as a "signal" – fish tend to move upriver in response to freshets, in response to cooler water, and generally at higher flows. (Fish also tend to move during high tide). Higher flows and greater depth probably reduce probability of predation.
- Fish passage from river's main stem into tributaries – Fish passage from a river's main stem into tributaries will be blocked during low flows, possibly because of passage problems but also behaviorally it is thought that many tributary spawners will not enter a tributary until they are ready to spawn, and only when spawning conditions are favorable at the same time they are prepared to spawn. Poorly-designed culvert installations can cause height, velocity and turbulence barriers to fish that are enticed to move up tributaries during spawning flows.

Low flows can also affect rearing by reducing the water's area and depth. Hoh River has two stocks of Chinook (spring/summer and fall), coho, and steelhead – these stocks' abundance is currently generally limited by rearing area. Research shows that coho abundance is limited in the summertime by pool area and in wintertime by off-channel habitat such as side-channels, ponds, and oxbows (Cederholm and Scarlett, 1981; Narver, 1978; Peterson, 1980).

Low flows can affect juvenile outmigration. Springtime flows carry smolts seaward. Predation is the biggest cause of mortality at the juvenile life stage. Research shows that survival of outmigrating juveniles increases linearly with flow, and then levels off at higher flow levels. These studies were conducted where reservoir releases affected flow levels (e.g., municipal water supply, hydropower). In the Hoh River basin, springtime flows are primarily a function of snowmelt.

5.2.1 Redd Dewatering and Isolation

Flow reduction has the potential of dewatering redds on gravel or sand bars in the main channel or isolating the redds in river side channels. Dewatering causes direct mortality of embryos and alevins due to insufficient oxygen levels, dessication, waste metabolite toxicity, and thermal stress. Isolation of redds in side channels can result in mortality due to the above factors plus starvation and increased predation on the emergent fry.

Within the Hoh basin, the dewatering of redds or isolation of fish by low flows usually would become the most critical at the cusp between late spring/summer Chinook spawn timing and the beginning of fall Chinook spawning about Oct. 10. More extreme rain or overwinter precipitation conditions beginning earlier in the year could advance this to progressively affect earlier spawn timing (though this has not recently been experienced) or more late extreme dry conditions would merely extend the low flow period to later in the season causing later migratory and spawning groups of fall Chinook as was evidenced in 1987 and 2002. This timing of blocked upstream movement could become critical to the normal distribution and density of spawners and any subsequent surviving offspring if it extended into the middle of November (i.e., about the peak of fall spawning) or beyond.

5.2.2 Juvenile Isolation

Isolation of running juveniles can occur when flows within the Hoh River increase to levels that inundate side channels and then subsequently recede, stranding the fish in unconnected pockets of water. While this process is known to naturally occur, the effects of severely reduced river volumes can amplify mortality rates as the interconnectedness of side channels to the main channel is further reduced, such as by channel downcutting (see Chapter 3). Insufficient oxygen levels, dessication, waste metabolite toxicity, and thermal stress will increasingly affect juvenile salmonids as the length of time they are stranded in side-channels increases.

5.2.3 Spawning Adult Isolation

Low flows observed in late summer and fall of 1987 and 2002 caused water levels to become so shallow that fall Chinook were unable to move upstream beyond a point on the lower river near the G & L Shake Company (approximately RM 3.0). There was visual observation that all salmon attempting to pass certain riffles (especially the riffle at G&L Shake Road, RM 3.0) in 2002 by the end of October were unsuccessful and all were observed to fall back to the lower pool. There was consensus between WDFW and the Tribe that these conditions could critically threaten the fall Chinook run if they persisted for long. Therefore, both parties curtailed their respective fisheries and began making hydraulic modifications at RM 3.0 to facilitate fish passage. Fortunately, in both years rains occurred in time that the low flow conditions did not last long enough to critically affect escapement levels. Possible relationship of such low flows to climate conditions are analyzed in some detail in Section 5.3.

5.2.4 Other Limiting Factors in the Hoh Basin

Although the focus of this assessment is flow-related passage, several other salmonid habitat limiting factors have been identified by Smith (2000). Anthropogenic (human) activities have created access problems for fish migrating up and down the Hoh River. The construction of roads in riparian zones, some of which closely parallel the streams, can confine the channel and disconnect potential off-channel (floodplain) habitat, and increase sediment inputs into the stream. Culverts can also block fish passage and prevent upstream migration. Logging waste wood left over from salvage operations (cedar spalts) has a tendency to impede water flows leading to warmer water temperatures and can also degrade water quality by leaching in tannins (Smith, 2000)

Increase in landslides in the Hoh River basin has resulted in a reduction of macroinvertebrates, which is an indicator of salmonid habitat quality and a food web item for salmonids. Fine sediment deposition in channels may accumulate in spawning gravels and degrade critical spawning habitat.

Loss of off-channel habitat lowers production of salmonid species, particularly coho. Wetlands and vegetated depressions provide important stable habitat for over-wintering salmon and is the site of significant exchange between nutrient rich groundwater and surface water. Alteration of this habitat is likely contributing to degraded groundwater inputs and reduced water quality (Smith, 2000).

Water quality problems such as a reduction in dissolved oxygen, increased acidity, and increased water temperatures have worked to decrease the quality of salmon habitat. These water conditions appear to result in a lack of aquatic invertebrates that the fish need for food. Alterations to the alluvial aquifers may be responsible for the degraded water quality. Removal of upland vegetation has decreased the infiltration of groundwater into the hillslopes and reduced baseflows into the Hoh which, in turn, reduces aquatic productivity and water temperature buffering (Smith, 2000).

5.3 Correlation of Flows with Climate

Low river flows during the summers of 1987 and 2002 impeded fish passage in the Hoh River. These low flows may be related to climate variability in the Hoh River watershed. Future climate change may lead to further declines in river flows and fish passage could be adversely impacted on a regular basis. One purpose of this assessment is to provide a rough conceptual model of how streamflows may respond to predicted climate change. It is important to remember that predicted climate changes are uncertain, as are the hydrologic impacts related to climate change.

5.3.1 Runoff Processes in the Hoh River Watershed

The Hoh River watershed (Figure 5-1) receives an average of 150 inches of annual precipitation, making it one the wettest regions in the United States. The bulk of the rainfall occurs in the winter and spring. The summer months of June through August average a total of only 10 inches of precipitation, or just 7 % of the annual average.

Streamflows in the Hoh River are typical of streams on the Olympic Peninsula. Flow levels peak in the early winter in response to increased rainfall, and typically peak again in the early summer as a response to snowmelt in the upper elevation areas. Peak flows are highest in the winter, and individual storm hydrographs during the winter are considered “flashy” because they respond quickly to rainfall then recede sharply after storms. The thin soils, shallow bedrock, and steep terrain that is prevalent throughout much of the watershed allows for little groundwater storage and recharge. Instead, rainfall moves quickly from the hillslopes to the tributary channels, and then down to the main stem of the Hoh River.

The upper portion of the Hoh River watershed is considered a "transient–snow" basin because winter precipitation falls as a mix of rain and snow. Snowfall in the upper watershed is very important because snowmelt in the spring helps sustain river levels in the summer and fall. Glaciers at the top of the watershed also play a key role in maintaining summer and fall flows. In effect both the snowfall and the glaciers act as storage reservoirs that store water in the winter and release it when air temperatures increase in the summer and early fall. Without these storage reservoirs, baseflows would be much lower because there is little rainfall or release from groundwater storage during the summer.

5.3.2 Climate Change Impacts

Most projected climate change scenarios show that the Pacific Northwest will become warmer and wetter in the future. The University of Washington Climate Impacts Group predicts temperatures in the Pacific Northwest will increase through the foreseeable future. Precipitation is expected to increase by up to 9%, but this prediction is less certain. Regardless, increases in summer precipitation may be negligible given that little rain falls in the summer, and any increase in precipitation may be cancelled out by increased evapotranspiration resulting from higher temperatures.

Projected Increases in Temperature and Precipitation

(UW CIG, 2004)

Temperature Change	**Precipitation Change**	
Annual Average	Oct-Mar	Apr-Sept
2020s		
+ 2.7 ºF	8%	4%
2040s		
+ 4.1 ºF	9%	2%

The hydrologic cycle of transient snow basins, such as the Hoh, will be more impacted by climate change than rain-dominated or snow-dominated basins. A few degrees warming can dramatically shift precipitation over a large area in the upper basin from snowfall to rainfall. This reduced snowpack will lower summer streamflows. For example, a climate change model developed for a transient snow basin the Cascade Mountains, resulted in a 35% reduction in summer streamflows when temperatures were increased by 4.5°F, as is predicted to occur within 40 years (UW CIG, 2004).

Future warming will also affect the size of the glaciers in the upper watershed. Glaciers maintain equilibrium when the amount of water released from the glacier in the summer is equal to the amount of water deposited by snowfall in the winter. Research on glaciers in the Olympic Mountains indicates that global warming trends have altered this equilibrium, which is causing glaciers to shrink. It appears this shrinking is related to warmer winter temperatures, which has decreased snowfall and minimized the extent to which the glaciers are replenished over the winter (Conway and others, 1999). This trend is most pronounced over the past 20 years when the Blue and Cascade glaciers have lost, on average, 0.5 and 0.8 meters of water per year (Rasmussen and Conway, 2001). Because summer temperatures have remained fairly constant (Conway and others, 1999), the baseflow contribution from glacial runoff has probably not increased.

Unfortunately the data-set developed from glaciers in the Olympic Mountains is not large enough to fully account for the influences of natural climatic variability on glacier size. The Pacific Decadal Oscillation (PDO; 20-30 year cycles) and the El Nino/Southern Oscillation (ENSO; 2-3 year cycles) are natural cycles of Pacific Ocean sea temperatures that influence climate variability worldwide. In terms of their effects on Pacific Northwest climate, warm phase PDO and ENSO may result in reduced snowpack and lower summer streamflows, while cool phase cycles may increase both snowpack and summer streamflows. For the sake of clarity in this report, warm phase PDOs are referred to as dry phase and cool phase PDOs are referred to as wet phase.

Analysis of glaciers in the North Cascades suggests that the overall trend of shrinking glaciers is not simply a function of PDO influences. Cool PDO cycles appear to slow the rate of glacial recession in the Cascades but the net balance over time is that the glaciers are shrinking. Long-term estimates at the South Cascade Glacier, for example, suggest its volume has declined from 0.49 km^3 to 0.16 km^3 between 1650 and 2001 (Josberger and Bidlake, 2003).

The extent to which glacial runoff contributes to summer baseflow levels has not been quantified in the Hoh River watershed. Therefore, the future impact to streamflows resulting from receding glaciers is speculative. Clearly, some proportion of summer flows is derived from glaciers in the upper watershed. The receding glaciers will continue to supply water to the river as they melt and water that was previously stored in the glacier is moved out of the basin (and lost). As the glaciers shrink, the baseflow contribution will decrease, and this decline may be non-linear. If the glaciers melt completely, obviously their baseflow contribution will be zero. Under these conditions, baseflows would be supported only be summer rainfall and groundwater storage, both of which are small.

5.3.3 Streamflow Trends in the Hoh River

An analysis of historic streamflows at the Hoh River USGS gage (#12041200) near the Highway 101 bridge indicates that minimum flows have been generally declining since the 1960s. Figure 5-2 shows the average 7-day annual minimum flow from 1961-2003. For clarification, this flow represents the lowest average weekly flow in a given year. Although the natural variability is high, the linear trend clearly shows decreased minimum flows with time. Over the past forty years the 7-day minimum flow has decreased, on average, at a rate of about 5 cfs per year.

The two lowest years on record occurred in 1987 and 2002, when the 7-day minimum flow dropped below 300 cfs (Figure 5-2). In these years, fish passage was obstructed by lows flows in the Hoh River. Therefore, a 7-day minimum flow of 300 cfs may be considered a threshold for fish passage. If the trend shown in Figure 5-2 is linear and continues at the current rate, the average 7-day minimum flow in a given year will drop below the 300 cfs threshold by 2045.

Figure 5-3 depicts streamflows over the course of 1987 and 2002 relative to the long-term mean. In 1987 and 2002 streamflows in the Hoh River were not below normal from January to June, but began dropping below the long-term mean in about July. Figure 5-4 provides a more detailed view of this critical late summer/fall low flow period. The minimum flows occurred in October and early November in 1987 and 2002, which is about one month later than normal. During most years streamflow will begin to increase in the early fall as a response to precipitation. In 1987 and 2002 years, precipitation was minimal in the early fall and therefore allowed streamflows to decline into the fall. Total precipitation between August and October was about 3.1 inches in 1987 and 4.4 inches in 2002; compared to the long-term mean of 18.9 inches.

While summer flows are sustained by snowmelt and glacial runoff, fall streamflows are sustained by late summer and early fall rainfall because much of the snowpack is gone and decreased temperatures limit runoff from glaciers. Fall streamflows can drop to low levels during years when fall precipitation is minimal, as evidenced in 1987 and 2002. If snowmelt and glacial runoff become negligible, the typical summer flows will likely resemble the fall flows in 1987 and 2002 because the summer precipitation is generally very low. General climate predictions are for longer drier summers. Fall streamflows during dry years will likely drop to even lower levels.

Figure 5-5 shows the most recent flows in 2005 relative to 1987, 2002, and the long-term mean. In May 2005 streamflows were quite high relative to the long-term mean, and is interpreted to be a response to precipitation. But streamflows dropped dramatically in June 2005, and illustrates how quickly the river can decline to very low levels in the early summer. It appears that late summer and early fall flows this year could drop to levels similar to those measured in 1987 and 2002, depending on precipitation patterns.

5.3.4 Effects of PDO Cycles on Streamflow

The 1961-2003 streamflow data-set for the Hoh River is somewhat incomplete because it does not include a complete wet/dry PDO cycle. Streamflow data are available from 1927-1963 at an upstream gage on the Hoh river, and these two gages together span a complete PDO cycle, and more importantly, each data set spans a dry portion of a PDO cycle. The older gage was situated upstream of the more recent gage so the data are not directly comparable, but the two gages can be analyzed independently to illustrate the effects of the PDO cycles.

Figure 5-6 shows the 7-day annual minimum streamflows at the two historic gages on the Hoh for two dry phase and one wet phase PDO. The PDO cycles appear to have some influence on minimum streamflows. The effects are more pronounced in the more recent data set (1961-2003), where the mean annual streamflow during the wet phase was about 16% higher than during the most recent dry phase (1977-1998). In the older data (1927-1963), the mean streamflow during the wet phase was only 8% higher than the following dry phase.

The recent declines in streamflows in the Hoh River are not simply residual effects of PDO cycles. One interesting observation is that the minimum flows measured at the old gage during the 1925-1946 dry PDO phase are about 6% higher than the minimum flows measured at the current gage during the most recent dry phase (1977-1998). This trend is quite unusual because the drainage basin area the older gage is about 20% less than that of the downstream gage. In other words, discharge at the upstream gage should lower than the downstream gage under similar climatic conditions, not higher, because numerous tributaries increase flows in the Hoh River as you move downstream. This anomaly may represent long-term changes reflecting global warming influences.

Based on the available data it seems reasonable to conclude that climate change is contributing to declines in baseflows in the Hoh River. The exact effect of climate change versus PDO cycles is difficult to quantify because the data-set on the Hoh River is small compared to the length of a typical PDO cycle. However, recent minimum flows appear to be lower than historical flows and this can be explained by a change in hydrologic processes associated with climate change. Furthermore, the general consensus of the scientific community is that warming is occurring and will likely result in decreased summer streamflows (UW CIG, 2004).

5.3.5 Projected Future Water Balance

A water-balance analysis can be used to show potential changes in future streamflows in the Hoh River. The water balance is particularly useful in this context because the contributions from snowmelt can be minimized to reflect future streamflow scenarios. Data from the recent work conducted by the Bureau of Reclamation (BoR) were used to characterize current and future monthly streamflows under changing climate conditions. Figure 5-7 shows mean monthly streamflows for 1) the historical period of record, 2) as simulated by the BOR, and 3) adjusted for possible future climate conditions.

The current conditions model was developed by the Bureau of Reclamation (BoR) and included in the WRIA 20 Phase II Technical Assessment (Golder, 2004), with the only difference being that the basin outlet in this report is at the USGS gage instead of the mouth of the river. The future conditions models include projected climatic changes in the year 2040, as predicted by the UW CIG (2004) . Monthly precipitation is increased by 9% from October to March and by 2% from April to September. Monthly temperatures are increased by 4.1° F over the entire year. Evapotranspiration estimates were obtained by taking the values calculated by the BoR and increasing them proportionally to the projected increase in monthly temperatures.

The simulated current conditions (BoR) tend to underestimate the average monthly summer flows and overestimate the fall flows relative to the measured USGS data. At the USGS gage, the lowest mean monthly streamflow occurs in October, while the predicted value occurs in July. These differences are related to monthly distribution of snowmelt in the BOR water balance model. Also, the BOR water balance does not consider the soil moisture deficit that accumulates over the summer, which is a potential reason why the measured streamflows are lower than predicted in the fall. At the same time, the principle concerns are the minimum flows and the predicted minimum flow in July is within 30% of the measured minimum flow in October. Based on the number of simplifying assumptions in the water balance, a 30% error is not unreasonable. Regardless, analysis based on the BoR simulations to characterize the future response of streamflow to climate change remain valid with respect to the trends derived.

The future conditions models are best used as index of potential future streamflows relative to the predicted current conditions. The intent is to illustrate how changing conditions can lead to drastically reduced minimum flows. The projected future conditions probably underestimate the minimum flows given that the predicted current conditions under estimate actual minimum flows by 30%. However, the projected flows are so low that a 30% error does not impact the general trends. For example, a 50% reduction in snowpack results in a mean July streamflow of 390 cfs, which is very close to 300 cfs fish passage threshold. Under the worst case scenario of 25% snowpack, July flows are reduced to just 150 cfs. Even if this scenario is off by 30%, the July minimum flows are still well below 300 cfs.

These projected future conditions are based on simple, back of the envelope calculations, and should not be considered 100% accurate. Projecting climatic change is not a simple science, and the hydrologic response to this change is also difficult to predict. Regardless, the water balance models clearly illustrate how projected climate change could have devastating consequences to streamflows, and fisheries, in the Hoh River.

5.4 Possible Solutions

Salmonids typically have a return cycle of several years. In a quadrennial cycle (such as is typical for Chinook; returning after four years), if one year's run is compromised by conditions such as low flows, diminished returns will be observed four years later as an "echo." Although the predominance of one year's run may adhere to a four-year cycle, some of that run will return in three or five years, and restore the one year's run that was compromised. This maintains the resilience of the complete run to episodic deleterious events. However, if conditions such as low flows are repeated too frequently, the entire run may be at risk. For this reason, and in the face of predicted significant changes in the flow regime of the Hoh River, appropriate responses should be formulated. Such responses are presented below in the form of hatcheries and stream flow augmentation.

5.4.1 Fish Hatchery

In the event that recurring low flows significantly affect the viability of natural salmonid runs, a fish hatchery may fulfill a sustaining role. A prospective hatchery site may be considered from just above Owl Creek at River Mile 27 down to near Morgan's Crossing at River Mile 22.

5.4.2 Flow Augmentation

The principal habitat component being addressed is the low flows in the later summer through mid-fall. Fish encounter obstacles (tree falls, small cascades, etc.) naturally during migration and typically wait for precipitation events to overcome the obstacles. Unfortunately, if current trends persist, the Hoh River will be deficient in water quantity to the point that precipitation may not occur with sufficient quantity or frequency to allow a fish population to migrate past obstacles without an elevated mortality. Flow augmentation on the Hoh River during dry periods can allow migrating fish to overcome the obstacles blocking upstream migration. Reservoir waters stored upstream of the low flow barriers to fish passage could be released in adequate quantities during fish migration to allow passage to upstream spawning habitat.

Historic flow data has been made available by the United States Geological Survey (USGS Gage #12041200) by an active stream gage at RM 15.4, approximately 250 feet downstream from U.S. Highway 101. It appears that stream flows as low as 300 cfs impede upstream fish migration near the G&L Shake Co. reach of the river (approximately RM 3.0).

Reservoir construction at one of more locations along the Hoh River or its tributaries could allow for the storage of surface water for release during critical low flow periods when fish passage is affected. Fish passage is dependent upon river stage. The amount of flow augmentation is dependent upon channel geometry to obtain the required increase in river stage to allow fish to overcome the obstacle. Therefore, a stage-flow relationship for a specific fish passage site is needed to determine flow levels that would provide adequate depth for fish passage.

However, predicted changes in mean monthly flows (Figure 5-7) are almost directly proportional to changes in snowmelt contributions. If a 25% reduction of snow melt contribution occurs under future climate change, stream baseflows are predicted to decrease approximately 25%. (Most of the summer baseflow is derived from snow melt, with minor amounts from precipitation and groundwater.) Given that the current critical low flow relative to fish passage is 300 cfs, a 25% augmentation would be 75 cfs. Therefore a range of 50-100 cfs augmentation is considered.

Salmonids do not require a continuous supply of high flows. During low flow periods, they typically congregate below a passage obstacle until a freshet or runoff pulse is generated by rains. Because augmentation at high rates would require a large reservoir, smaller reservoirs are considered with controlled pulse releases. This will allow more judicious use of the available stored water. Ramping up and ramping down of releases may be needed to avoid flushing of juveniles (if present) and stranding during the release of each pulse. Typical ramping rates are on the order of a rise of one inch in river stage per hour. This is an operational concern with large changes in released flows, and may not be a significant with respect to the flows being considered in this application. Site specific studies would have to be conducted to determine appropriate ramping rates.

Necessary flow augmentation can be estimated using the following assumptions:

- Augmentation flows of 50 to 100 cfs;
- Augmentation water supplied in 12 or 24-hour pulses; and,
- Two to ten augmentation events occur.

5.4.2.1 Reservoir Sites

Flow augmentation and reservoir storage calculations require data on precipitation and basin size above the proposed dams. For the purposes of this study, we have considered two dams on Owl Creek, one dam on Maple Creek, and one dam on Nolan Creek (Figures 5-8 through 5-11). Owl Creek is a stream that flows west from the upland area on the south side of Huelsdonk Ridge, south of the Hoh River. At the base of Huelsdonk Ridge, Owl Creek flows north across a glacial drift plain before entering the Hoh River. Maple Creek is a small basin south of Owl Creek that also flows west from the upland areas on the south side of the Hoh River. Like Owl Creek, Maple Creek flows north across a glacial drift plain before entering the Hoh River. Nolan Creek is located in the lower Hoh Valley and flows into the Hoh River at approximately River Mile 6. While a reservoir on Nolan Creek would address the low flow fish barrier at River Mile 3, it will not be able to address low flow barriers higher in the valley should they develop as a result of changing channel morphology.

Estimated runoff from annual precipitation in these catchments was significantly more than the estimated reservoir volumes (Tables 5-2 through 5-4). Therefore, annual precipitation is not a limiting factor in reservoir sizing.

The estimated augmentation water volumes range from a minimum of approximately 100 acre-feet for two pulse of 50 cfs augmentation for 12 hours duration, to a maximum of approximately 2,000 acre-feet for ten pulses of 100 cfs augmentation for 24 hour duration. Number of pulses and flow levels for each storage volume are detailed in Tables 5-5 through 5-8. Storage volumes are largely a function of dam height (Table 5-4).

As Tables 5-5 through 5-8 demonstrate, preliminary estimates for storage volumes for proposed reservoirs on both Owl (Site No. 1) and Maple Creeks show that a dam 120 feet high would be required to meet the larger flow augmentation demand of the ten 24-hour, 50 to 100 cfs augmentation events for Maple Creek and 60 to 100 cfs for Owl Creek Site No. 1.

An 80-foot high dam constructed on Owl Creek Site No. 1 would allow for a storage volume of approximately 1,044 acre-feet. For Owl Creek Site No. 1 this water volume would meet up to ten 12-hour flow augmentation pulses for flows of 50 – 100 cfs. For the 24-hour pulse, an 80-foot dam height at Owl Creek Site No. 1 would allow up to 10 pulses at 50 cfs, or five pulses at 100 cfs. For the full range of water volumes, number of pulses, and flow levels on Owl Creek Site No. 1, see Table 5-5.

An 80-foot high dam constructed on Owl Creek Site No. 2 would allow for a storage volume of approximately 908 acre-feet. This water volume would meet up to ten 12-hour flow augmentation pulses for flows of 50 – 90 cfs. For the 24-hour pulse, an 80-foot dam height at Owl Creek Site No. 2 would allow up to five pulses at 90 cfs. For the full range of water volumes, number of pulses, and flow levels on Owl Creek Site No. 2, see Table 5-6.

An 80-foot high dam on Maple Creek would have a storage volume of 856 acre-feet. This water volume would meet up to ten 12-hour flow augmentation pulses for flows of up to 80 cfs. For the 24-hour pulse, an 80-foot dam height on Maple Creek, this storage volume would allow up to five pulses at 80 cfs. For the full range of water volumes, number of pulses, and flow levels on Maple Creek, see Table 5-7.

An 80-foot high dam on Nolan Creek would have a storage volume of 1,847 acre-feet. This water volume would exceed the required water volume needed for ten 12-hour flow augmentation pulses for flows of up to 100 cfs. For the 24-hour pulse, an 80-foot dam height on Nolan Creek, this storage volume would allow up to ten pulses at 90 cfs. For the full range of water volumes, number of pulses, and flow levels on Nolan Creek, see Table 5-8.

5.4.2.2 Limitations Associated with Streamflow Augmentation

Limitations on the feasibility of augmenting streamflows with a surface water reservoir are:

- Costs associated with reservoir construction in remote area;
- Reservoir permitting; and,
- Geotechnical suitability of any proposed location.

Sediment runoff from the catchment into a reservoir will eventually diminish the reservoir capacity. Sediment may be primarily natural from unstable slopes. Additional sediment may be generated from forest harvest. It is understood that a significant portion of the Owl Creek drainage has been logged, potentially creating slope stability problems in the area and the associated generation of additional sediment. Infilling of a reservoir by sediment may reduce the operational life of a surface water reservoir.

5.4.3 Channel Modification

The objective of channel modification would be to increase river depth in problematic areas. Reducing channel width to increase depth by emplacement of sandbags, engineered logjams, coffer dams or more permanent structures can address fish passage problems in low-depth reaches.

Fish passage is limited by the depth of flow (i.e. stage), not necessarily the volume of flow (i.e. discharge). While flow depths are a function of flow volumes, the exact stage-discharge relationship at any point on a river is controlled by the dimensions of the channel. It may be possible, through engineered channel modifications, to increase flow depths without altering flow volumes.

In the past sand bags have been used as a temporary modification tool to increase flow depths on the Quillayute River. Essentially, the sand bags are used to constrict the flow and increase flow depths. Similar permanent structures, such as rocks or logs, could be constructed in the channel for the same effect. Engineered logjams are particularly effective because they create aquatic habitat, in addition to their engineered applications.

Channel modification is only an effective solution if fish passage problems are limited to isolated areas in the channel. If the area around the G& L Shake Company is the only area of concern, then channel modification is probably the most effective strategy. However, numerous other areas of concern are known to exist upstream, but the location of these areas may not be discovered until the fish are able to pass the area by the G& L Shake Company during times of critical low flows. Furthermore, additional problem areas could arise in the future due to lower minimum flows or natural channel morphological changes.